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Cao et al.

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(54) **READER SIDE SHIELD**

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(21) Appl. No.: **14/514,050**

(22) Filed: **Oct. 14, 2014**

Related U.S. Application Data

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(51) **Int. Cl.**

G11B 5/31	(2006.01)
G11B 5/11	(2006.01)
G11B 5/39	(2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/3163*** (2013.01); ***G11B 5/112*** (2013.01); ***G11B 5/39*** (2013.01); ***G11B 5/3903*** (2013.01); ***G11B 5/3906*** (2013.01); ***G11B 5/3912*** (2013.01); ***G11B 5/3929*** (2013.01); ***G11B 5/3932*** (2013.01); *Y10T 29/49032* (2015.01); *Y10T 29/49041* (2015.01); *Y10T 29/49043* (2015.01); *Y10T 29/49046* (2015.01); *Y10T 29/49048* (2015.01)

(58) **Field of Classification Search**
CPC G11B 5/3163; G11B 5/39; G11B 5/3903; G11B 5/3906; G11B 5/3929; G11B 5/3932; G11B 5/112; G11B 5/3912; Y10T 29/49032; Y10T 29/49041; Y10T 29/49043; Y10T 29/49046; Y10T 29/49048
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,673,163 A *	9/1997	Cohen	G11B 5/3163 360/125.51
6,201,673 B1 *	3/2001	Rottmayer	G11B 5/3903 360/324.12
6,980,403 B2	12/2005	Hasegawa	
8,066,892 B2	11/2011	Guthrie et al.	
8,120,874 B2	2/2012	Hsiao et al.	
8,335,058 B2	12/2012	Xue et al.	
8,347,488 B2	1/2013	Hong et al.	
8,422,168 B2	4/2013	Hsiao et al.	
8,451,562 B2	5/2013	Pentek et al.	
2007/0035888 A1 *	2/2007	Sbiaa	G11B 5/3906 360/324.1
2008/0117552 A1 *	5/2008	Zhou	G11B 5/3932 360/319
2012/0184053 A1 *	7/2012	Sakamoto	G11B 5/3163 438/3
2013/0021697 A1	1/2013	Dimitrov et al.	

FOREIGN PATENT DOCUMENTS

JP 10284769 A * 10/1998

* cited by examiner

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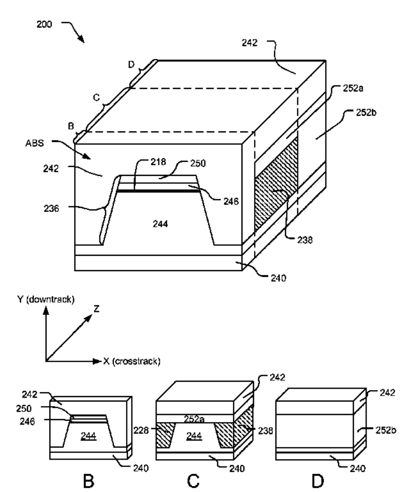
(57) **ABSTRACT**

A magnetoresistive (MR) sensor shield shields against both down track and cross-track interference. The shield can be formed in a single deposition step. In one implementation of the disclosed technology, a "tail" portion of the shield is eliminated by including a non-magnetic material adjacent to opposite sides of a middle portion of the sensor stack.

12 Claims, 10 Drawing Sheets



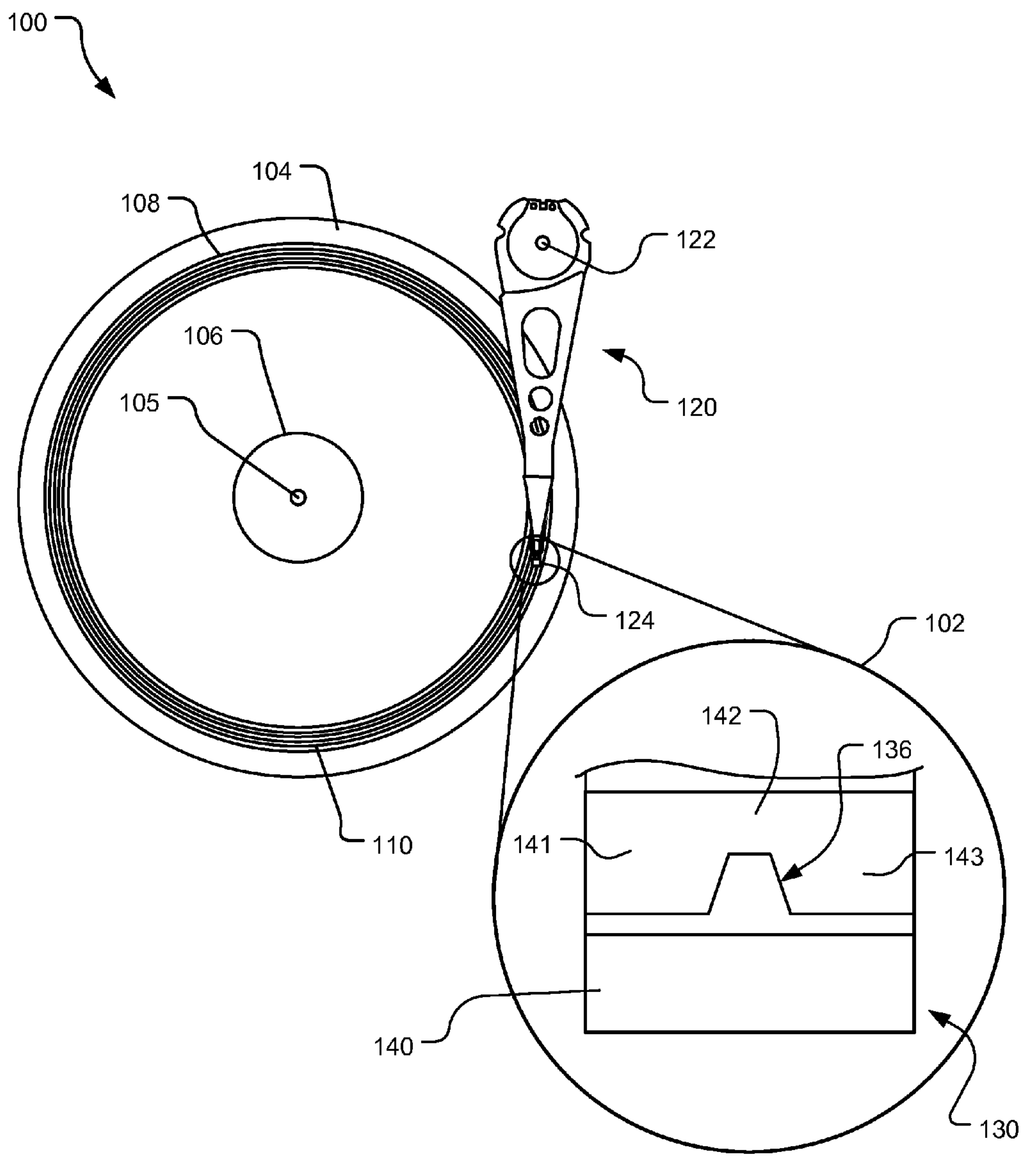


FIG. 1

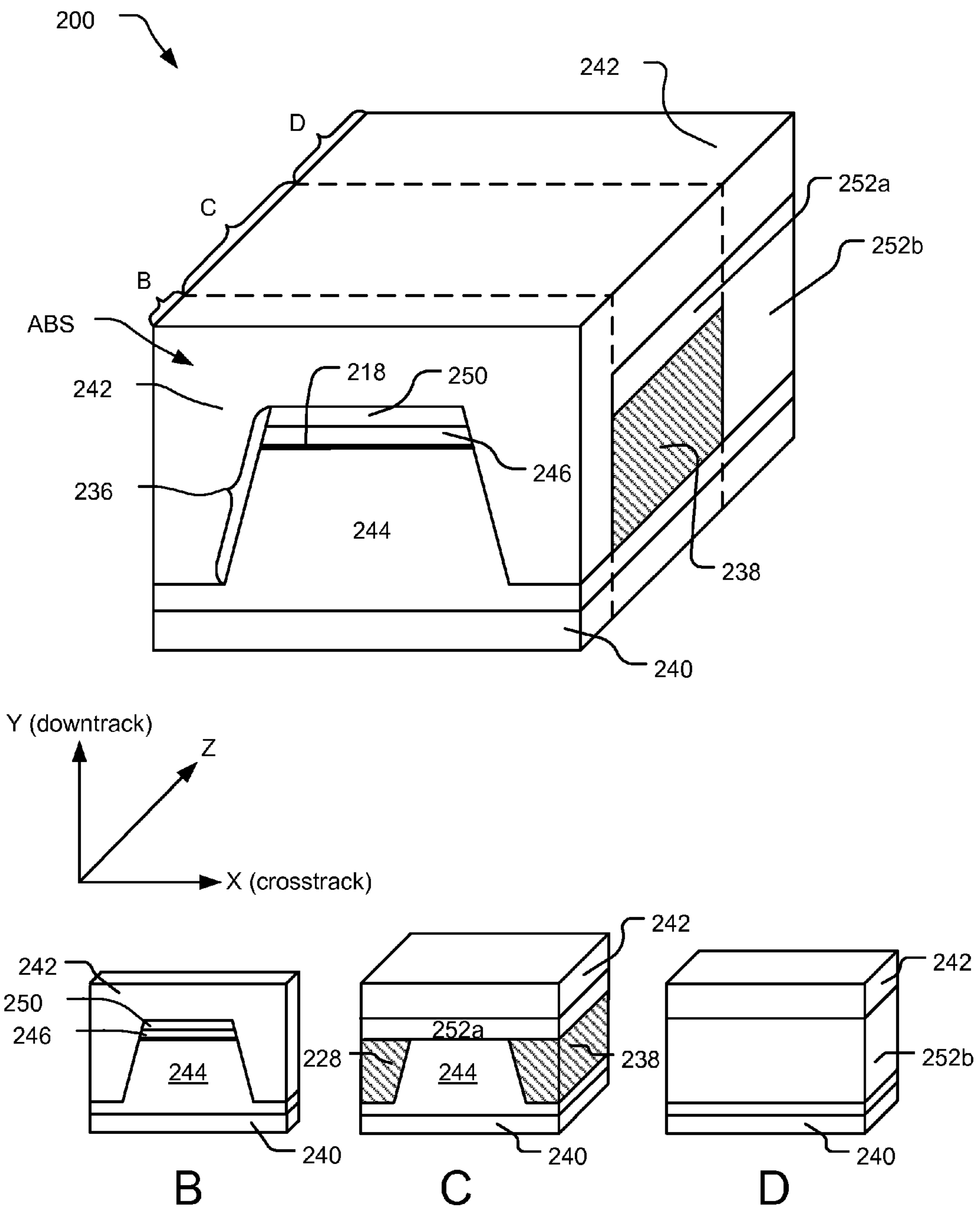

200
242
D
C
252a
252b
B
ABS
242
218
250
246
236
244
238
240
Y (downtrack)
Z
X (crosstrack)
242
250
246
244
240
242
252a
228
244
238
240
242
252b
240
B
C
D

FIG. 2

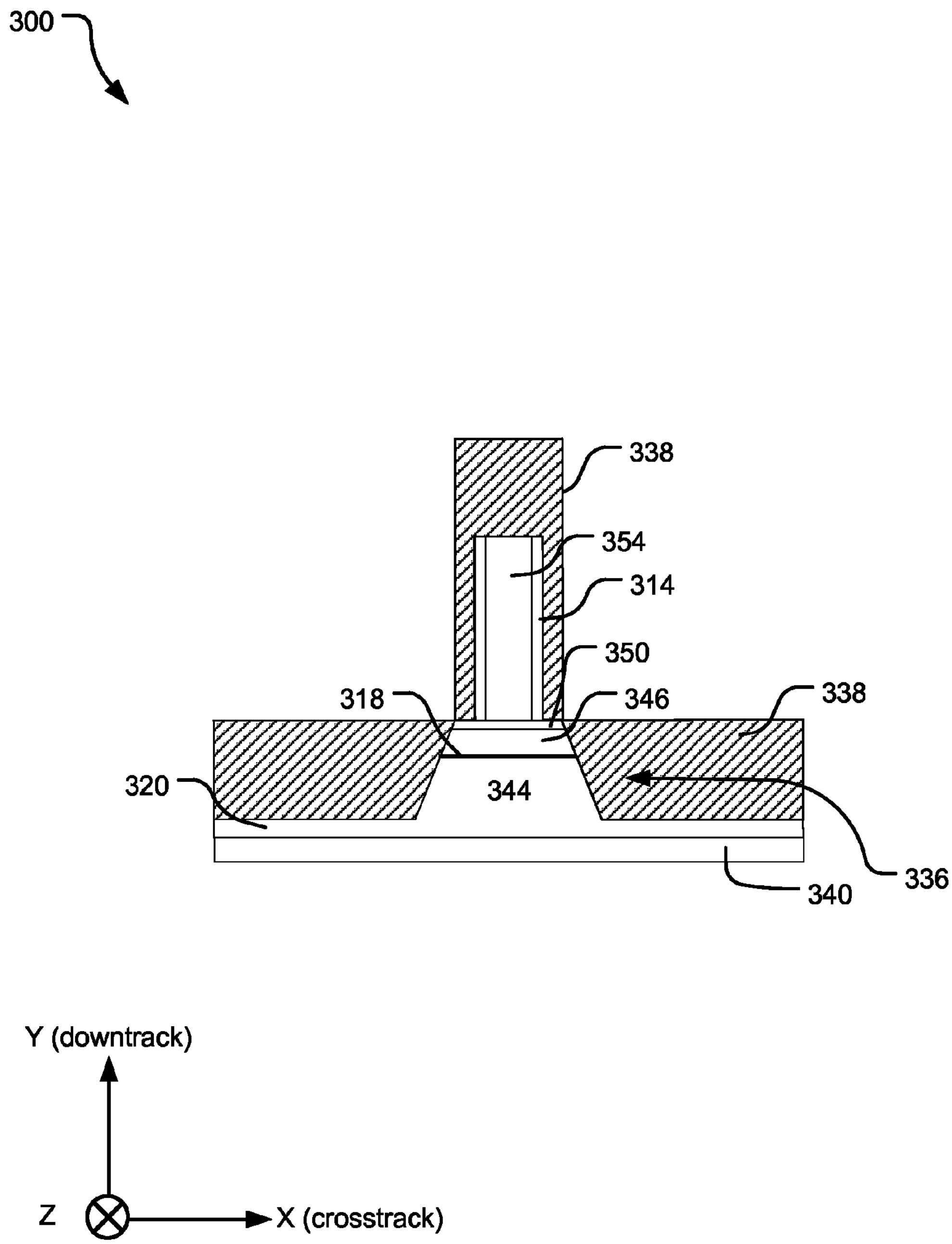

300
338
354
314
350
318
346
338
320
344
336
340
Y (downtrack)
Z
X (crosstrack)

FIG. 3

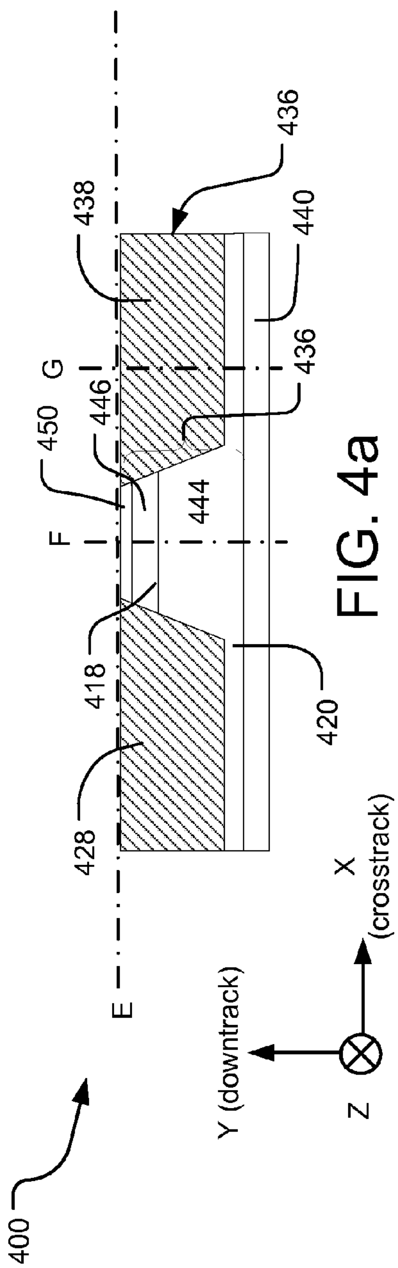


FIG. 4a

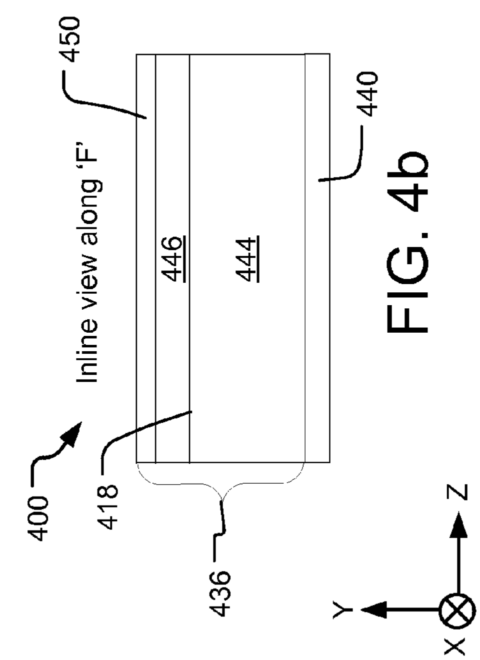


FIG. 4b

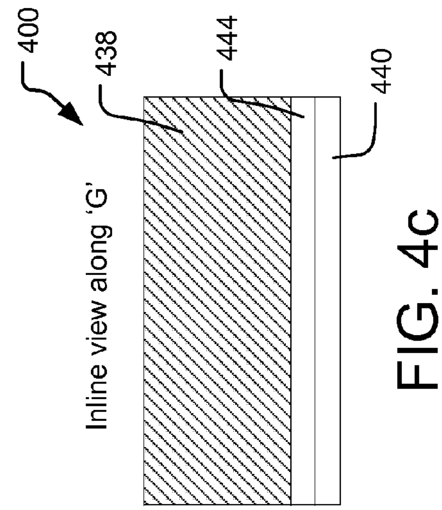


FIG. 4c

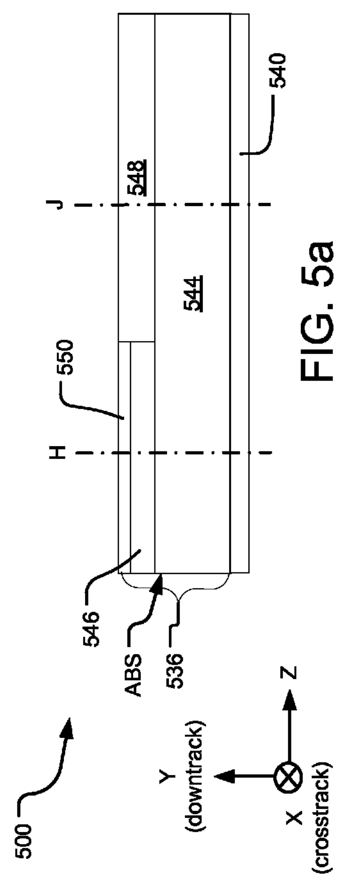


FIG. 5a

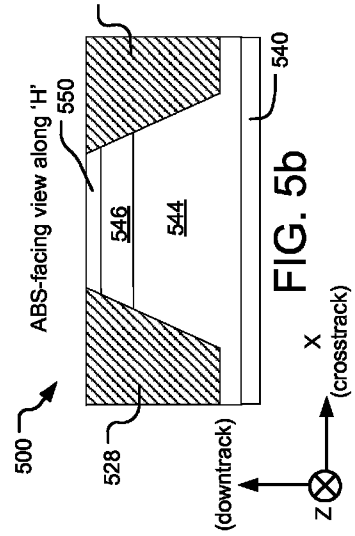


FIG. 5b

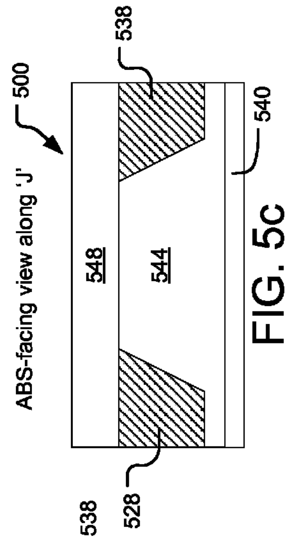


FIG. 5c

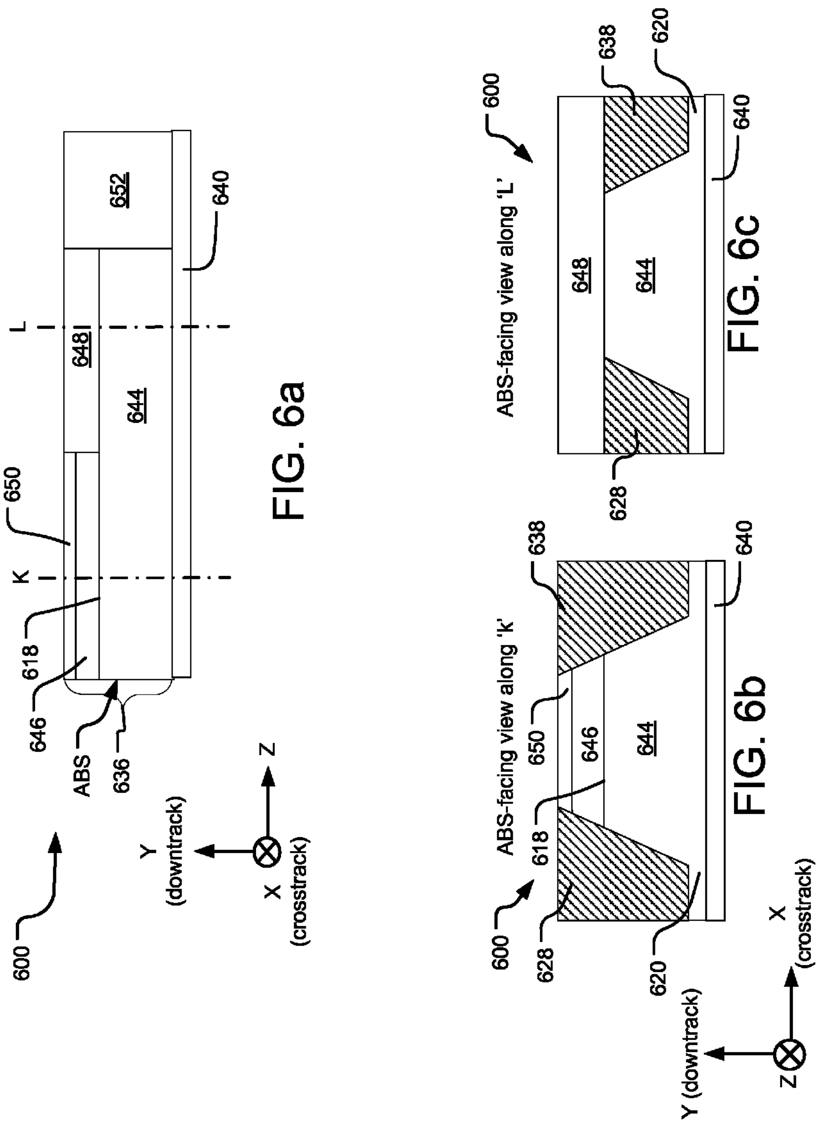


FIG. 6a

FIG. 6b

FIG. 6c

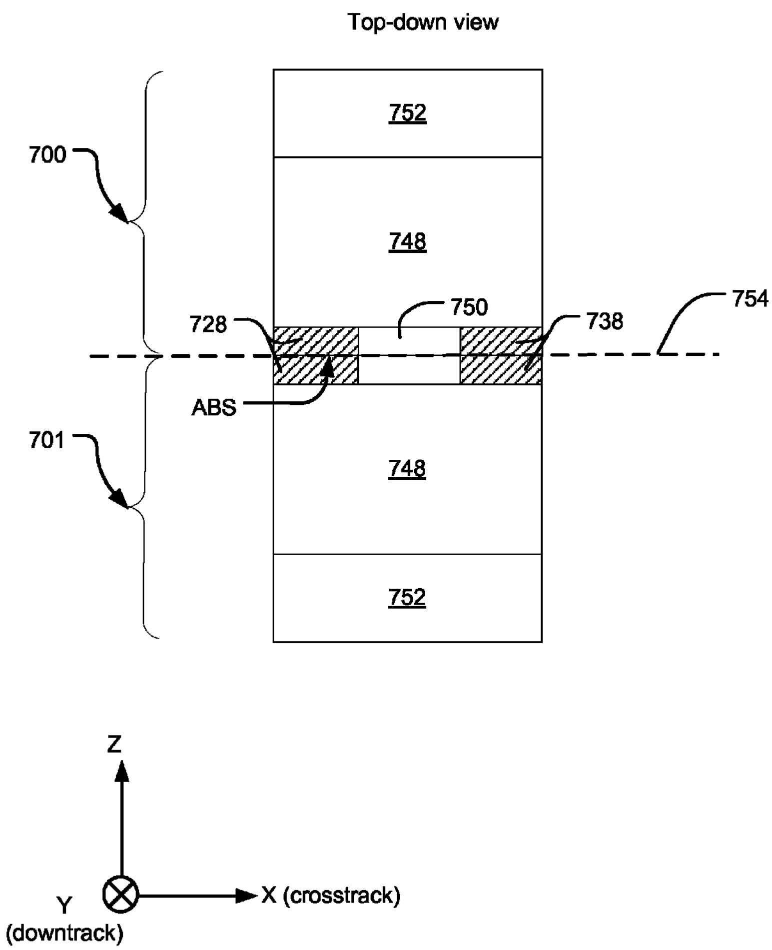

Top-down view
752
700
748
750
754
728
738
ABS
701
748
752
Z
Y
(downtrack)
X (crosstrack)

FIG. 7

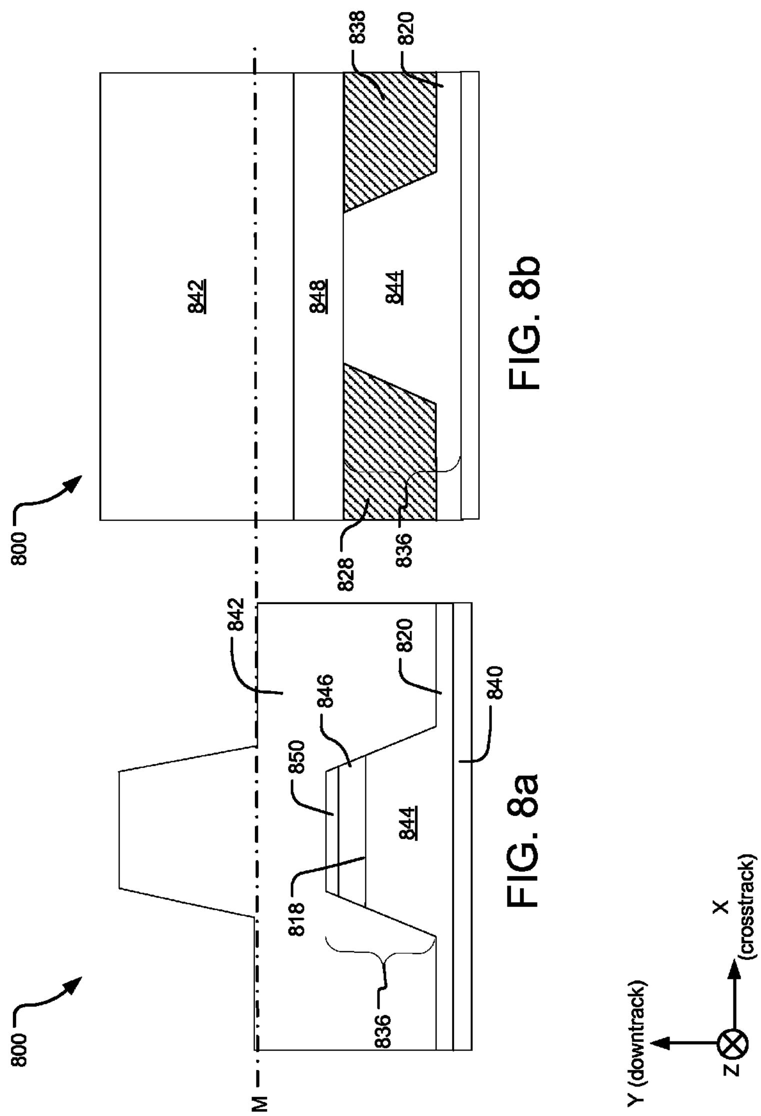

800
842
848
844
838
820
828
836
800
842
846
850
844
818
836
820
840
M
Y (downtrack)
X (crosstrack)
Z

FIG. 8b

FIG. 8a

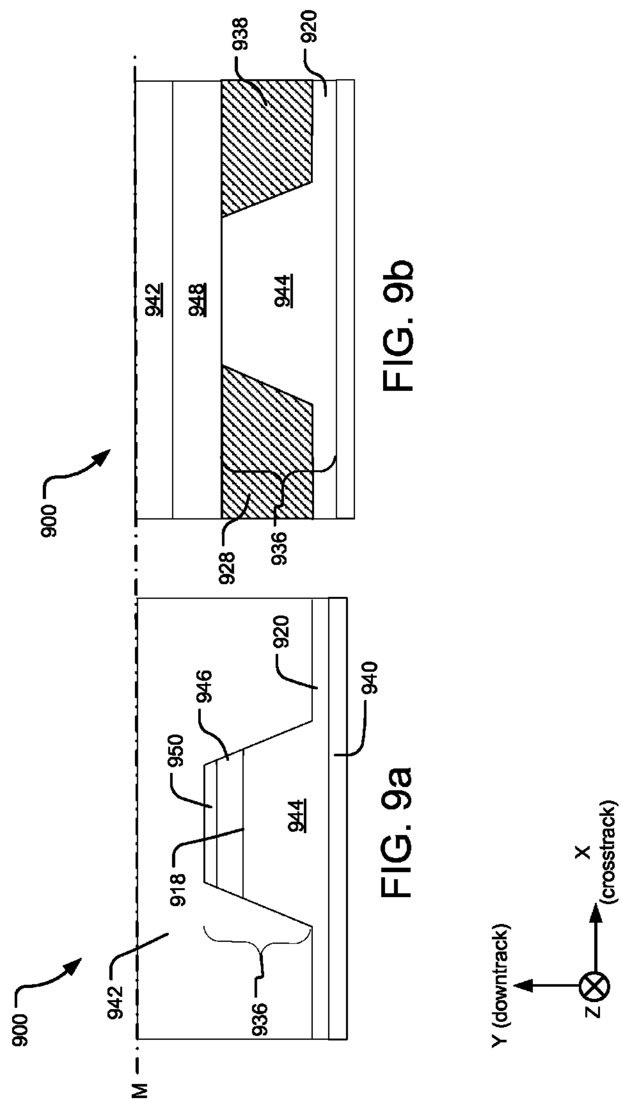

900
942
948
944
938
920
928
936
900
942
936
918
950
946
944
920
940
M
Y (downtrack)
X (crosstrack)
Z

FIG. 9a

FIG. 9b

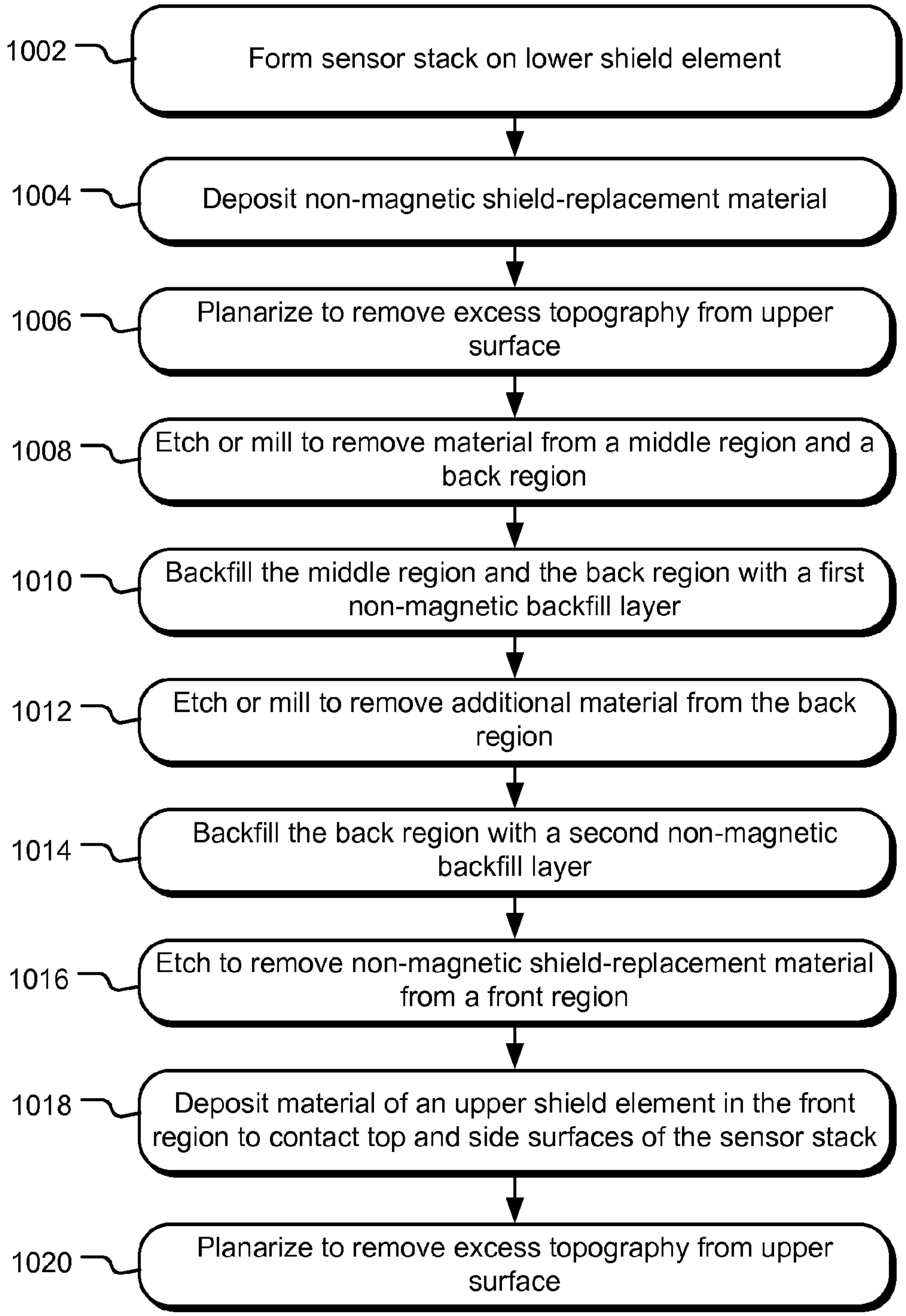

1002
Form sensor stack on lower shield element
1004
Deposit non-magnetic shield-replacement material
1006
Planarize to remove excess topography from upper surface
1008
Etch or mill to remove material from a middle region and a back region
1010
Backfill the middle region and the back region with a first non-magnetic backfill layer
1012
Etch or mill to remove additional material from the back region
1014
Backfill the back region with a second non-magnetic backfill layer
1016
Etch to remove non-magnetic shield-replacement material from a front region
1018
Deposit material of an upper shield element in the front region to contact top and side surfaces of the sensor stack
1020
Planarize to remove excess topography from upper surface

FIG. 10

READER SIDE SHIELD

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application Ser. No. 61/890,747, entitled "Reader Side Shield," and filed on Oct. 14, 2013, which is specifically incorporated by reference for all it discloses or teaches.

BACKGROUND

Generally, magnetic hard disc drives include transducer heads that read and write data encoded in tangible magnetic storage media. Magnetic flux detected from the surface of the magnetic medium causes rotation of a magnetization vector of a sensing layer or layers within a magnetoresistive (MR) sensor within the transducer head, which in turn causes a change in electrical resistivity of the MR sensor. The change in resistivity of the MR sensor can be detected by passing a current through the MR sensor and measuring the resulting change in voltage across the MR sensor. Related circuitry can convert the measured voltage change information into an appropriate format and manipulate that information to recover the data encoded on the disc.

As improvements in magnetic recording density capabilities are pursued, the dimensions of transducer heads continue to shrink. Typically, transducer heads are formed as a thin film multilayer structure having an MR sensor, among other structures. In some approaches, the thin film multilayer structure includes a synthetic anti-ferromagnet (SAF) to enhance MR sensor stability. However, existing thin film process and structure designs used in forming SAF-based MR sensors present effects that can nevertheless limit MR sensor performance and stability.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Other features, details, utilities, and advantages of the claimed subject matter will be apparent from the following more particular written Detailed Description of various implementations and implementations as further illustrated in the accompanying drawings and defined in the appended claims.

Implementations described and claimed herein address the foregoing by providing for formation of an upper shield element of a magnetoresistive (MR) sensor in a single deposition operation, the upper shield element adjacent to a top surface and a side surface of a sensor stack.

According to another implementation, a non-magnetic material is deposited adjacent opposite sides of a sensor stack. The non-magnetic material is removed from a front portion of the MR sensor proximal to an ABS and magnetic shield material is deposited on the front portion between the ABS and the first non-magnetic material.

Other embodiments are also described and recited herein.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIG. **1** illustrates a data storage device having an example MR sensor formed by a process of the described technology.

FIG. **2** illustrates a three-dimensional view of an example MR sensor (i.e., View A) with a wrap-around upper shield element and filler material situated behind a sensor stack.

FIG. **3** illustrates an ABS-facing view of a front portion of an MR sensor at an early stage of an MR sensor manufacturing process.

FIG. **4***a* illustrates an ABS-facing view of a front portion of MR sensor at an early stage of an MR sensor manufacturing process

FIG. **4***b* illustrates an inline view of an MR sensor taken along a plane F of FIG. **4***a*.

FIG. **4***c* illustrates an inline view of an MR sensor taken along a plane G of FIG. **4***a*.

FIG. **5***a* illustrates an inline view of another example MR sensor at an intermediate stage of an MR sensor manufacturing process.

FIG. **5***b* illustrates an ABS-facing view of a front portion of an MR sensor taken along a plane H of FIG. **5***a*.

FIG. **5***c* illustrates an ABS-facing view of a middle portion of an MR sensor taken along a plane J of FIG. **5***a*.

FIG. **6***a* illustrates an inline view of another example MR sensor at another intermediate stage of an MR sensor manufacturing process.

FIG. **6***b* illustrates an ABS-facing view of a front portion of an MR sensor taken along plane K of FIG. **6***a*.

FIG. **6***c* illustrates an ABS-facing view of a middle portion of an MR sensor taken along plane L of FIG. **6***a*.

FIG. **7** illustrates a top-down view (in the x-z plane) of an MR sensor at another stage of an MR manufacturing process.

FIG. **8***a* illustrates ABS-facing view of a front portion of another example MR sensor at a later stage of an MR sensor manufacturing process.

FIG. **8***b* illustrates an ABS-facing view of a middle portion the MR sensor of FIG. **8***a*.

FIG. **9***a* illustrates an ABS-facing view of a front portion of another example MR sensor.

FIG. **9***b* illustrates an ABS-facing view of a middle portion of another example MR sensor **900**.

FIG. **10** illustrates example operations for manufacturing an MR sensor.

DETAILED DESCRIPTIONS

In some implementations, MR sensors are formed as a multilayer structure or stack in a thin film process. The MR sensor stack includes a first magnetic layer, called a "free" layer (FL), and a second magnetic layer, called a "reference layer" (RL). The free layer represents a sensing layer that responds to changes in magnetic flux detected from the surface of the magnetic surface (e.g., the magnetizing vector of the free layer rotates), while the response of the reference layer to such changes in magnetic flux are inhibited by a pinned layer (PL) which is separated from the reference layer by a thin nonmagnetic spacer layer. The reference layer, thin nonmagnetic spacer layer, and pinned layer act as an antiferromagnetic layer called a synthetic anti-ferromagnet (SAF) layer. In some configurations, an antiferromagnetic (AFM) material is deposited adjacent to the pinned layer to pin the magnetization of the pinned layer. In this manner, the MR sensor stack is further stabilized by the AFM layer. The MR sensor stack also includes a non-magnetic barrier layer separating the free layer from the reference layer. In this configuration, the free layer provides a free magnetization orientation M_F direction substantially perpendicular to a reference magnetization orientation M_R direction provided by the pinned layer.

The MR sensor is stabilized against the formation of edge domains, which can move and thereby result in electrical noise that makes data recovery difficult. Such stabilization can be achieved using a permanent magnet abutted junction design. In this scheme, permanent magnets with high coercive field (i.e., hard magnets) are placed at each end of the sensor. The field from the permanent magnets stabilizes the MR sensor by preventing edge domain formation and further providing proper bias. The MR sensor can also be stabilized by soft magnets with low coercive field instead of permanent magnets. In this scheme, the soft magnets act as side shields to improve sensor performance. An SAF structure may be deposited on top of the side shield to stabilize the side shield structure.

FIG. **1** illustrates a data storage device **100** having an example MR sensor, shown in more detail in an exploded view **102**, formed by a process of the described technology. Although other implementations are contemplated, in the illustrated implementation, the data storage device **100** includes a storage medium **104** (e.g., a magnetic data storage disc) on which data bits can be recorded using a magnetic write pole and from which data bits can be read using an MR sensor **130** (shown in the exploded view **102** as a portion of a transducer head assembly **124**). The storage medium **104** rotates about a spindle center or a disc axis of rotation **105** during rotation, and includes an inner diameter **106** and an outer diameter **108** between which are a number of concentric data tracks **110**. It should be understood that the described technology may be used with a variety of storage formats, including continuous magnetic media, discrete track (DT) media, shingled media, bit patterned media (BPM), etc.

Information may be written to and read from data bit locations in the data tracks **110** on the storage medium **104**. The transducer head assembly **124** is mounted on an actuator assembly **120** at an end distal to an actuator axis of rotation **122**. The transducer head assembly **124** flies in close proximity above the surface of the storage medium **104** during disc rotation. The actuator assembly **120** rotates during a seek operation about the actuator axis of rotation **122**. The seek operation positions the transducer head assembly **124** over a target data track for read and write operations.

The exploded view **102** schematically illustrates an air-bearing surface (ABS) view of an MR sensor **130**. The MR sensor **130** includes a monolithic shield including a bottom shield element **140**, a top shield element shield **142**, and side shield elements **141** and **143**. In another implementation, the top shield element **142** has a multi-layer structure that helps to stabilize the side shield elements **141** and **143**. Each of the elements **141**, **142**, and **143** of the monolithic shield is part of an integrated shield formed in a single deposition operation.

The MR sensor **130** further includes a sensor stack **136** located between the bottom shield **140** and the top shield **142** along a down track (y) direction. The top shield **142** wraps around the sensor stack **136** such that it is adjacent to opposite sides of the sensor stack in the cross track (x) direction.

In one implementation, the bottom shield **140** is an AFM stabilized bottom shield that shields and provides stabilization to the sensor stack **136**. The sensor stack **136** includes a plurality of layers (not shown) that perform a plurality of different functions. In one implementation, a non-magnetic shield-replacement material (not shown) is included in a region behind the sensor stack **136** to further stabilize the MR sensor **130**.

FIG. **2** illustrates a three-dimensional view of an example MR sensor **200** (i.e., View A) with a wrap-around upper shield element **242** and non-magnetic shield-replacement material **228**, **238** situated behind a sensor stack **236**. When describing various MR sensors and MR sensors herein, three axes are used to describe the perspective of the accompanying figure. The X-axis represents a cross-track axis. A cross-sectional view of the Y-Z plane taken from a position along the X-axis is referred to herein as an “inline” view. The Y-axis represents the down track axis, which is also typically the axis of thin film processing (e.g., the reader stack grows along the Y axis). The Z-axis represents the air bearing surface (ABS) axis, such that any figure depicted in a plane that is orthogonal to the Z axis represents a surface or cross-section that is parallel to the ABS. Thus, a cross-sectional view of the X-Y plane taken from a position along the Z-axis is referred to herein as an ABS-facing view.

Views B, C, and D are illustrative of 3-dimensional “portions” (e.g., slices) of the MR sensor **200**, respectively corresponding to a front portion B, a middle portion C, and a back portion D of the MR sensor **200**. The front portion B (also referred to as the ABS-portion) is, in operation, situated closest to an adjacent a rotating media. The back portion D is, in operation, situated furthest from the adjacent rotating media. The terms “front portion,” “middle portion,” and “back portion” are used throughout the application to refer to the relative positions of illustrated cross-sections within the MR sensor **200** and/or other MR sensors.

The MR sensor **200** includes a plurality of layers that perform a plurality of functions. In various implementations, the number of such layers and their associated functions may vary. However, the MR sensor **200** has a sensor stack **236** that includes a synthetic antiferromagnetic (SAF) structure **244** and a free layer **246**. In one implementation, the SAF structure **244** includes a reference layer separated from a pinned layer by a non-magnetic spacer layer. The reference layer is magnetically coupled to the pinned layer and the pinned layer has a a magnetic orientation that is pinned in a set direction. The SAF structure **244** is separated from the free layer **246** by a nonmagnetic barrier layer **218**. The free layer **246** has a magnetic moment that is free to rotate under the influence of an applied magnetic field. Additionally, the sensor stack **236** includes a capping layer **250**. Other implementations may have layers in addition to or in place of those shown and described in FIG. **2**.

The MR sensor further includes a lower shield element **240** and a wrap-around upper shield element **242** that wraps around three sides of the sensor stack **236**. The lower element **240** and the wrap-around upper shield element **242** are adjacent to opposite sides of the sensor stack **236** along the down track (y) direction. The lower shield element **240** and the wrap-around upper shield element **242** isolate the sensor stack **236** from electromagnetic interference, primarily z-direction interference, and serve as electrically conductive first and second electrical leads connected to processing electronics (not shown). In one implementation, the lower shield element **240** and wrap-around upper shield element **242** permit the sensor stack **236** to be affected by magnetic fields of a data bit adjacent an ABS of the sensor stack **236** while reducing or blocking magnetic field interference of other, adjacent data bits.

In addition to protecting the sensor stack **236** along the down track direction, the wrap-around upper shield element **242** wraps around a portion of the sensor stack **236** to protect the sensor stack **236** from cross-track electromagnetic interference as well. According to one implementation, the wrap-around upper shield element **242** is deposited in a single step. This reduces or eliminates coupling concerns that arise when side shields are deposited separately from the top shield.

A non-magnetic backfill layer includes a stripe isolation region **252***a* and a back region **252***b*. The stripe isolation region **252** extends within a middle region of the MR sensor **200** and has an ABS-facing surface adjacent to the sensor stack **236**. The back region **252***b* extends within a back portion of the MR sensor **200** and is separated from the sensor stack **236** by the stripe isolation region **252***a*.

When the MR sensor **200** is implemented in a storage device, the sensor stack **236** is situated between the ABS adjacent a rotating media and the non-magnetic backfill layer **238**. The stripe isolation region **252***a* of the non-magnetic backfill layer is axially aligned (e.g., along the z-axis) with the free layer **246** and the back region **252***b* of the non-magnetic backfill layer is aligned axially (e.g., along the z-axis) with both the free layer **246** and the SAF structure **244**.

In one implementation, the non-magnetic backfill layer, including the stripe isolation region **252***a* and back region **252***b*, is one or more layers of alumina (AlO_3) or silicon dioxide (SiO_2).

The MR sensor **200** further includes non-magnetic shield-replacement regions **228**, **238** (best visible in View C) that are formed on opposite sides of the sensor stack **236** in the cross-track direction. The non-magnetic shield-replacement regions **228** and **238** are separated from the ABS by material of the upper shield element **242** (best visible in View B). The non-magnetic shield-replacement regions **228** and **238** increase stability of the MR sensor **200**, and are made of non-magnetic material that is both mechanically and chemically stable.

A mechanically stable material is a material that is not stressed during wafer fabrication, read/write head formation, or during read/write operations of a recording head. A material may be "stressed" if it degrades performance of the recording head or causes damage to the recording head, such as thin film delamination. A chemically stable material a material that can withstand both the wafer fabrication and read/write head formation without causing corrosion or chemical changes to the material. For example, a chemically stable material is chemically inactive during wafer lift-off, chemical-mechanical planarization (CMP), milling, etc.

Materials suitable for use in the non-magnetic shield-replacement regions **228**, **238** may have a mill rate that is equal to or less than the mill rate of materials of the wrap-around upper shield element **242** (e.g., NiFe). In one implementation, material of the non-magnetic shield-replacements **228** and **238** is a material that can be selectively etched using a fluorocarbon (CF_4) or an oxygen-based plasma. In another implementation, material of the non-magnetic shield-replacement regions **228** and **238** is removable by a commercially available wet etch solution (e.g., METEX Copper striper). Other implementations are also contemplated.

Example materials satisfying one or more of the above-described criteria include without limitation silicon dioxide (SiO_2), amorphous carbon, and copper. The non-magnetic shield-replacement material (**228**, **238**) in the middle portion of the MR sensor **200** is included to replace a side shield tail that exists in some other MR sensors between the bottom shield element **240** and the stripe isolation region **252***a*. The resulting MR sensor **200** exhibits improved stability over these other MR sensors.

Various formation phases of the MR sensor **200** are shown and described in greater detail with respect to FIGS. **3-9**. It should be understand that FIGS. **3-9** may each relate to the same implementation (e.g., the implementation of FIG. **2**) or to one or more implementations different from FIG. **2** and/or one another.

FIG. **3** illustrates an ABS-facing view of a front portion of an example MR sensor **300** at an early stage of an MR sensor manufacturing process. The MR sensor **300** includes a sensor stack **336** formed on a lower shield **340**. The sensor stack **336** has a plurality of layers, including an AFM layer **320**, a free layer **346**, an SAF structure **344**, a nonmagnetic barrier layer **318**, and a capping layer **350**. Additional layers are also contemplated.

A photomask **354** is formed on the sensor stack **336** to protect the sensor stack **336** during one or more subsequent deposition processes. In one implementation, the photomask **354** is a hardened structure formed by applying droplets of a liquid photoresist across the MR sensor **300** and exposing portions of the liquid photoresist to a high intensity light. The high intensity light changes the solubility of either the exposed or unexposed portions (depending on the type of photoresist). The unchanged portions are removed by a developer solution, leaving behind the photomask **354**.

One or more milling operations may be performed to prepare the MR sensor for deposition of a non-magnetic shield replacement material **238**. During these milling operations, redeposition material **314** may form on the photomask **354**. Thereafter, non-magnetic shield-replacement material **338** is deposited substantially evenly across the MR sensor **300** on both the sensor stack **336** and the photomask **354**. The non-magnetic shield-replacement material **338** is a non-magnetic material that can be removed by an etching process. In one implementation, the non-magnetic shield-replacement material **338** is removable by etching with CF_4 or an Oxygen-based plasma. In another implementation, the non-magnetic shield-replacement material **338** is removed by a commercially available wet etch solution. Suitable materials include, for example, (SiO_2), amorphous carbon, and copper.

FIGS. **4***a*-**4***c* illustrate an example MR sensor **400** at an early stage of an MR sensor manufacturing process. FIG. **4***a* illustrates an ABS-facing view of a front portion of the MR sensor **400**. FIG. **4***b* illustrates an inline view of the MR sensor **400** taken along plane F shown in FIG. **4***a*. FIG. **4***c* illustrates an inline view of the MR sensor **400** taken along plane G shown in FIG. **4***a*.

The MR sensor **400** includes a lower shield **440** and a sensor stack **436**. Non-magnetic shield-replacement regions **428** and **438** are formed on opposite sides of the sensor stack **436** along the cross-track direction. The sensor stack **436** has a plurality of layers, including an AFM layer **420**, a free layer **446**, an SAF structure **444**, a nonmagnetic barrier layer **418**, and a capping layer **450**. Additional layers are also contemplated.

The MR sensor **400** is planarized along a plane 'E' that is substantially perpendicular to an ABS. This planarization is performed to remove excess topography from the upper surface of the MR sensor (e.g., the photomask and the overlying non-magnetic shield-replacement material shown in FIG. **3**). The planarization is accomplished using one or more lapping, polishing, milling, or chemical-mechanical planarization (CMP) operations.

FIGS. **5***a*-**5***c* illustrate another example MR sensor **500** at another stage in an MR manufacturing process. FIG. **5***a* illustrates an inline view of the MR sensor **500** taken through an x-axis center of the MR sensor **500**. FIG. **5***b* illustrates an ABS-facing view of a front portion of the MR sensor **500** taken along plane H in FIG. **5***a*. FIG. **5***c* illustrates an

ABS-facing view of a middle portion of the MR sensor **500** taken along plane J in FIG. **5***a*.

Material has been removed from a free layer **546** and a capping layer **550** in both middle and back portions of a sensor stack **536**. This removal process can be accomplished by a milling or etching operation that leaves an underlying SAF structure **544** and a lower shield element **540** substantially in-tact. The area previously including the material removed from the free layer **546** and the capping layer **550** is backfilled with a non-magnetic backfill layer **548**, which may be alumina or silicon dioxide. The backfill operation can be performed via one or more standard deposition processes.

FIGS. **6***a*-**6***c* illustrate another example MR sensor **600** at another stage in an MR manufacturing process. FIG. **6***a* illustrates an inline view of the MR sensor **600** taken through an x-axis center of MR sensor **600**. FIG. **6***b* illustrates an ABS-facing view of a front portion of the MR sensor **600** taken along plane K in FIG. **6***a*. FIG. **6***c* illustrates an ABS-facing view of a middle portion of the MR sensor **600** taken along plane L in FIG. **6***a*.

The MR sensor **600** includes a lower shield element **640**, non-magnetic shield-replacement elements **628** and **638**, a first non-magnetic backfill layer **648**, a second non-magnetic backfill layer **652**, and a sensor stack **636**. The sensor stack **636** further includes an AFM layer **620**, an SAF structure **644**, a free layer **646**, a capping layer **650**, and a nonmagnetic barrier layer **618**.

A milling or etching operation removes material from the first non-magnetic backfill layer **648**, the AFM layer **620**, and the SAF structure **644** in a back portion of the MR sensor **600**. In one implementation, the material is removed via a milling operation that is performed while a photomask (not shown) is in place protecting the illustrated portions of the first backfill layer **648** and of the sensor stack **636**. For example, the material of the first non-magnetic backfill layer **648** and sensor stack **646** may be milled away in the back portion of the MR sensor **600** to expose the lower shield element **640**. Other implementations may have layers in addition to or in place of those shown and described in FIG. **6**.

The back portion of the MR sensor **600** is backfilled with material of the second non-magnetic backfill layer **652**. In one implementation, the non-magnetic backfill layer **652** is alumina. In one implementation, the non-magnetic backfill layer **652** is silicon dioxide.

FIG. **7** illustrates a top-down view (in the x-z plane) of other example MR sensors **700** and **701** at another stage of an MR manufacturing process. The two MR sensors **700** and **701** are formed at simultaneously and subsequently severed along the separation axis **754**. According to one implementation, the illustrated MR sensor **700** is the same MR sensor illustrated in FIGS. **6***a*-**6***c*, and at the same stage of manufacturing. Visible layers of MR sensor **700** include a first non-magnetic backfill layer **748**, a second non-magnetic backfill layer **752**, and non-magnetic shield-replacements **728** and **738**. The non-magnetic shield-replacements **728** and **738** each include a "tail portion" that extends within z-plane and below the first non-magnetic backfill layer **748** (see, e.g., FIG. **6***c*). Material of the non-magnetic shield-replacements **728** and **738** that is visible in FIG. **7** is removed via a selective etching process.

FIGS. **8***a*-**8***b* illustrate another example MR sensor **800** at another stage in an MR manufacturing process. FIG. **8***a* illustrates an ABS-facing view of a front portion of the MR sensor **800**. FIG. **8***b* illustrates an ABS-facing view of a middle portion of the MR sensor **800**. The MR sensor **800** includes a lower shield element **840**, an upper shield element **842**, non-magnetic shield-replacements **828** and **838**, a non-magnetic backfill layer **848**, and a sensor stack **836**. The sensor stack **836** further includes a capping layer **850**, a nonmagnetic barrier layer **818**, a free layer **846**, an SAF structure **844**, and an AFM layer **820**. Non-magnetic shield-replacement material previously surrounding the sensor stack **836** in a front portion of the MR sensor **800** (such as that shown in FIGS. **6***b* and **7**) has been etched away. An upper shield element **842**, which may be a soft magnetic material, is deposited, in a single step, substantially evenly across the MR sensor **800**. As shown in FIG. **8***a*, the upper shield element **842** substantially surrounds the front portion of the reader stack.

FIGS. **9***a*-**9***b* illustrate another example MR sensor **900** at another stage in an MR manufacturing process. FIG. **9***a* illustrates an ABS-facing view of a front portion of the MR sensor **900**. FIG. **9***b* illustrates an ABS-facing view of a middle portion of the MR sensor **900**. The MR sensor **900** includes a lower shield element **940**, an upper shield element **942**, non-magnetic shield-replacements **928** and **938**, a non-magnetic backfill layer **948**, and a sensor stack **936**. The sensor stack **936** further includes a capping layer **950**, a free layer **946**, a nonmagnetic barrier layer **918**, an SAF structure **944**, and an AFM layer **920**. Excess material (e.g., material shown in FIG. **8***a*) of an upper shield element **942** is removed by a milling or polishing operation so that the MR sensor **900** is substantially planarized along a plane 'M.'

FIG. **10** illustrates example operations for manufacturing an MR sensor. A formation operation **1002** forms a sensor stack on a lower shield element of an MR sensor. The formation operation **1002** includes one or more individual deposition and etching operations to pattern and form the MR sensor. Thereafter, a deposition **1004** operation deposits non-magnetic shield-replacement material substantially evenly across the MR sensor. In one implementation, the non-magnetic shield-replacement material is a non-magnetic material that can be selectively removed via a wet or dry etching process. Suitable materials include without limitation silicon oxide, amorphous carbon, and copper. The amount of material deposited may be sufficient to bring the non-magnetic shield-replacement material into contact with the top edges of the sensor stack.

A planarization operation **1006** planarizes an upper surface of the MR sensor, exposing a top layer of the sensor stack. The planarization operation **1006** is accomplished using one or more lapping, polishing, milling, or chemical-mechanical planarization (CMP) operations.

An etching or milling operation **1008** removes sensor stack material from a middle portion and a back portion of the MR sensor. In particular, the milling or etching operation **1008** removes material from a free layer, a capping layer, as well as one or more additional layers, while leaving an SAF structure of the sensor stack substantially in tact across front, middle, and back portions of the MR sensor. The layers affected by the milling or etching operation **1008** may remain substantially in-tact within a front portion of the MR sensor.

A backfill operation **1010** backfills the etched or milled areas of the middle and back portions with a first non-magnetic backfill layer. This backfilling may be performed using or more standard deposition techniques.

Another etching or milling operation **1012** removes material from the back portion of the MR sensor. In one implementation, material in the back portion is milled away to expose a lower shield element. For example, substantially all material of the first non-magnetic backfill layer and the sensor stack may milled away from the back portion.

Another backfill operation **1014** backfills the back portion affected by the etching or milling operation **1012** with a second non-magnetic backfill layer. In one implementation, the second non-magnetic backfill layer is alumina.

An etching operation **1016**, which may be a wet or dry etch, removes substantially all of the non-magnetic shield-replacement material from the front portion of the MR sensor. In one implementation, the etching operation **1016** does not substantially affect non-magnetic shield-replacement material in the middle portion of the MR sensor that underlies the first non-magnetic backfill layer. This remaining non-magnetic shield-replacement material is included as a filler to assume the place of a side shield tail that may otherwise form consequent to the MR sensor manufacturing process. The resulting MR sensor exhibits improved stability over MR sensors including the side shield tail.

A deposition operation **1018** deposits upper shield material in the front portion of the MR sensor so that a resulting wrap-around upper shield element substantially surrounds both the top of the sensor stack and opposite sides of the sensor stack in the cross-track direction. The wrap-around shield element is deposited in a single step and that acts as both a top shield and side shields. A planarization operation **1020** planarization a top surface of the MR sensor to remove excess surface topography. To further stabilize the MR sensor, a second upper shield (not shown herein) with a pinned structure may be deposited on the MR sensor to pin the magnetic field of the wrap-around shield.

The above specification, examples, and data provide a complete description of the structure and use of exemplary implementations of the technology. Since many implementations of the technology can be made without departing from the spirit and scope of the technology, the invention resides in the claims hereinafter appended. Furthermore, structural features of the different implementations may be combined in yet another implementation without departing from the recited claims.

What is claimed is:

1. A method of forming a magnetoresistive (MR) sensor comprising:

depositing a first non-magnetic material adjacent opposite sides of a sensor stack in a cross-track direction;

removing the first non-magnetic material from an air bearing surface (ABS) region of the MR sensor while leaving the first non-magnetic material in-tact in a middle region of the MR sensor; and

depositing magnetic shield material within the ABS region from which the first non-magnetic material was removed, the deposited magnetic shield material isolating the first non-magnetic material in the middle region from an ABS such that the deposited magnetic shield material is between the ABS and the first non-magnetic material.

2. The method of claim **1**, wherein depositing the shield material further comprises:

depositing, in a single deposition operation, the magnetic material to contact a top surface and a side surface of the sensor stack, the deposited magnetic material forming a monolithic shield including a top shield and two side shields.

3. The method of claim **2**, wherein the top surface of the sensor stack forms an edge with the side surface of the sensor stack.

4. The method of claim **2**, wherein the top surface and the side surface of the sensor stack are exposed by the removing operation.

5. The method of claim **1**, wherein the non-magnetic material is at least one of silicon dioxide (SiO_2), amorphous carbon, and copper.

6. The method of claim **1**, wherein the non-magnetic material is a material that can be selectively etched using at least one of fluorocarbon (CF_4), an oxygen-based plasma, and a wet etch solution.

7. The method of claim **1**, further comprising:

removing material of a free layer of the sensor stack from a middle portion of the sensor stack, the middle portion separated from an ABS by the ABS portion; and

backfilling the middle portion with a second non-magnetic material.

8. The method of claim **1**, wherein a second non-magnetic material is adjacent to the first non-magnetic material in a down-track direction.

9. A method comprising:

depositing a non-magnetic material adjacent opposite sides of a magnetoresistive (MR) sensor in a cross-track direction;

removing the non-magnetic material from an air bearing surface ABS region of the MR sensor to expose a top surface and a side surface of a sensor stack while leaving the non-magnetic material in-tact adjacent the opposite sides of the MR sensor in a middle region;

depositing magnetic shield material within the ABS region to contact the top surface and the side surface of the sensor stack, the deposited magnetic shield material forming a monolithic shield that isolates the non-magnetic material in the middle region from an ABS such that the deposited magnetic shield material is between the ABS and the non-magnetic material.

10. The method of claim **9**, wherein the monolithic shield includes a top shield element, a first side shield element on a side of a sensor stack, and a second shield element on an opposite side of the sensor stack.

11. The method of claim **9**, wherein the top surface forms an edge with the side surface of the sensor stack.

12. The method of claim **9**, wherein the removal operation does not remove the non-magnetic material from the middle portion of the MR sensor separated from the ABS by the ABS portion.

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